DNA VACCINES AGAINST TUMOR GROWTH AND METHODS OF USE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U. S. Provisional Application for Patent Serial No. 60/457,009 filed on March 24, 2003, the disclosure of which is incorporated herein by reference.

GOVERNMENTAL RIGHTS

This invention was made with government support under Grant Nos. 1R01CA83856-01 and CA83856 from the National Institutes of Health, Grant No. 9RT00-17 from the Tobacco Related Disease Research Program, and Grant Nos. DAMD17-02-1-0137 and DAMD17-02-1-0562 from the Department of Defense. The government has certain rights in the invention.

FIELD OF THE INVENTION

This invention relates to deoxyribonucleic acid (DNA) vaccines encoding suitable molecules effective for eliciting an immune response against tumor cells. More particularly this invention relates to DNA vaccines encoding for a cancer-associated Inhibitor of Apoptosis-family (IAP) protein, and an immunoactive gene product. This invention also relates to methods of using the DNA vaccines to inhibit tumor growth.

BACKGROUND OF THE INVENTION

Vaccines have been utilized to provide a long term protection against a number of disease conditions by very limited administration of a prophylactic agent that stimulates an organism's immune system to destroy disease pathogens before they can proliferate and cause a pathological effect. Various approaches to vaccines and vaccinations are described in Bernard R. Glick and Jack J. Pasternak, *Molecular Biotechnology, Principles and Applications of Recombinant DNA*, Second Edition, ASM Press pp. 253-276 (1998).

Vaccination is a means of inducing the body's own immune system to seek out and destroy an infecting agent before it causes a pathological response. Typically, vaccines are either live, but attenuated, infectious agents (virus or bacteria), or a killed form of the agent. A vaccine consisting of a live bacteria or

virus must be non-pathogenic. Typically, a bacterial or viral culture is attenuated (weakened) by physical or chemical treatment. Although the agent is nonvirulent, it can still elicit an immune response in a subject treated with the vaccine.

An immune response is elicited by antigens, which can be either specific macromolecules or an infectious agent. These antigens are generally either proteins, polysaccharides, lipids, or glycolipids, which are recognized as "foreign" by lymphocytes known as B cells and T cells. Exposure of both types of lymphocytes to an antigen elicits a rapid cell division and differentiation response, resulting in the formation of clones of the exposed lymphocytes. B cells produce plasma cells, which in turn, produce proteins called antibodies (Ab), which selectively bind to the antigens present on the infectious agent, thus neutralizing or inactivating the pathogen (humoral immunity). In some cases, B cell response requires the assistance of CD4 helper T cells.

The specialized T cell clone that forms in response to the antigen exposure is a cytotoxic T lymphocyte (CTL), which is capable of binding to and eliminating pathogens and tissues that present the antigen (cell-mediated or cellular immunity). In some cases, an antigen presenting cell (APC) such as a dendritic cell, will envelop a pathogen or other foreign cell by endocytosis. The APC then processes the antigens from the cells and presents these antigens in the form of a histocompatibility molecule:peptide complex to the T cell receptor (TCR) on CTLs, thus stimulating an immune response.

Humoral immunity characterized by the formation of specific antibodies is generally most effective against acute bacterial infections and repeat infections from viruses, whereas cell-mediated immunity is most effective against viral infection, chronic intracellular bacterial infection, and fungal infection. Cellular immunity is also known to protect against cancers and is responsible for rejection of organ transplants.

Antibodies to antigens from prior infections remain detectable in the blood for very long periods of time, thus affording a means of determining prior exposure to a pathogen. Upon re-exposure to the same pathogen, the immune system effectively prevents reinfection by eliminating the pathogenic agent before it can proliferate and produce a pathogenic response.

The same immune response that would be elicited by a pathogen can also sometimes be produced by a non-pathogenic agent that presents the same antigen as the pathogen. In this manner, the subject can be protected against subsequent exposure to the pathogen without having previously fought off an infection.

Not all infectious agents can be readily cultured and inactivated, as is required for vaccine formation, however. Modern recombinant DNA techniques have allowed the engineering of new vaccines to seek to overcome this limitation. Infectious agents can be created that lack the pathogenic genes, thus allowing a live, nonvirulent form of the organism to be used as a vaccine. It is also possible to engineer a relatively nonpathogenic organism such as *E. coli* to present the cell surface antigens of a pathogenic carrier. The immune system of a subject vaccinated with such a transformed carrier is "tricked" into forming antibodies to the pathogen. The antigenic proteins of a pathogenic agent can be engineered and expressed in a nonpathogenic species and the antigenic proteins can be isolated and purified to produce a "subunit vaccine." Subunit vaccines have the advantage of being stable, safe, and chemically well defined; however, their production can be cost prohibitive.

A new approach to vaccines has emerged in recent years, broadly termed genetic immunization. In this approach, a gene encoding an antigen of a pathogenic agent is operably inserted into cells in the subject to be immunized. The treated cells, preferably antigen presenting cells (APCs) such as the dendritic cells, are transformed and produce the antigenic proteins of the pathogen. These *in vivo*-produced antigens then trigger the desired immune response in the host. The genetic material utilized in such genetic vaccines can be either a DNA or RNA construct. Often the polynucleotide encoding the antigen is introduced in combination with other promoter polynucleotide sequences to enhance insertion, replication, or expression of the gene.

DNA vaccines encoding antigen genes can be introduced into the host cells of the subject by a variety of delivery systems. These delivery systems include prokaryotic and viral delivery systems. For example, one approach is to utilize a viral vector, such as vaccinia virus incorporating the new genetic material, to innoculate the host cells. Alternatively, the genetic material can be incorporated in a

plasmid vector or can be delivered directly to the host cells as a "naked" polynucleotide, i.e. simply as purified DNA. In addition, the DNA can be stably transfected into attenuated bacteria such as *Salmonella typhimurium.* When a patient is orally vaccinated with the transformed *Salmonella*, the bacteria are transported to Peyer's patches in the gut (i.e., secondary lymphoid tissues), which then stimulate an immune response.

DNA vaccines provide an opportunity to immunize against disease states that are not caused by traditional pathogens, such as genetic diseases and cancer. Typically, a genetic cancer vaccine introduces into APCs a gene that encodes an antigen, and the so transformed APCs produce antigens to a specific type of tumor cell. An effective general vaccine against a number of cancer types can thus entail numerous individual vaccines for each type of cancer cell to be immunized against.

Inhibitor of Apoptosis Proteins (i.e., IAP-family proteins) are a class of natural antigens expressed in many different tumor cells. As the name suggests, these proteins, in their natural form, inhibit apoptosis (i.e., programmed cell death), which in turn, may lead to resistance of cancer cells to apoptosis inducing chemotherapeutic agents, such as etoposide. Examples of IAP-family proteins include X chromosome-associated IAP (XIAP), NAIP, cIAP1 (also known as BIRC2), cIAP2 (also known as BIRC3), bruce (also known as BIRC6), survivin (also known as BIRC5), and livin (also known as BIRC7, KIAP, and ML-IAP). The mammalian IAP family of proteins includes proteins with three BIR domains (e.g., XIAP, cIAP1, cIAP2, and NAIP), as well as proteins with a single BIR domain (e.g., survivin and livin).

Tamm *et al. Cancer Res.* 1998; 58(23):5315-20, have reported expression of the human survivin in 60 human tumor cell lines. Tamm *et al.* have also reported that survivin and XIAP were both effective at inhibiting programmed cell death (apoptosis) induced by treatment of tumor cells with apoptosis inducing agents such as Bax or Fas (CD95). Survivin and other IAP-family proteins reportedly inhibit apoptosis by binding to effector cell death proteases, e.g., caspase-3 and caspase-7. Mutations in IAP-family proteins can lead to reduced apoptosis inhibition activity or even to apoptosis inducing activity relative to the

activity of the wild-type IAP-family protein. The anti-apoptotic activity of the IAP-family proteins is believed to be associated with the BIR domain.

Survivin reportedly is present in most common human cancer cells, including cancers of the lung, prostate, breast, and pancreas. Survivin has also been identified in high-grade, non-Hodgkin's lymphomas, but not in low-grade non-Hodgkin's lymphomas. Reportedly, survivin is present in normal cells during fetal development, but unlike most other IAP-family proteins, survivin is virtually undetectable in normal adult human tissues. *See* Ambrosini *et al. Nat. Med.* 1997; 3(8):917-21.

Livin has been detected in some adult tissues and in embryonic tissues. Elevated levels of livin expression have been reported in melanomas, colon cancer cells, bladder cancer cells, and lung cancer cells. Two splice variants of livin have been reported, both of which contain a single BIR domain. The full length alpha variant has 298 amino acid residues, whereas the beta variant has 280 amino acid residues.

IAP-family proteins also have been identified in a number of species in addition to humans, including mammals such as the mouse, amphibians such as *Xenopus* species (African clawed toads), insects such as *Drosophila* species, and baculoviruses.

The ubiquitous and highly selective nature of survivin expression in cancer cells makes it a potentially useful diagnostic marker for cancer. For example, Rohayem *et al. Cancer Res.* 2000; 60:1815-17, have reportedly identified auto-antibodies to survivin in human lung and colorectal cancer patients.

Survivin has also been identified as a target for cancer therapy. The inhibiting effect of survivin on caspase-3 and caspase-7 has been implicated in the resistance of cancer cells to various apoptosis stimulating chemotherapeutic treatments. An antisense oligonucleotide that targets survivin expression has been reported to down-regulate survivin expression in an adenocarcinoma cell line and sensitize the cancer cells to the chemotherapeutic agent etoposide. *See* Olie *et al. Cancer Res.* 2000; 60:2805-9; and Mesri *et al. J. Clinical Res.*, 2001; 108:981-990.

Cytokines are proteins and polypeptides produced by cells that can affect the behavior of other cells, such as cell proliferation, cell differentiation,

regulation of immune responses, hematopoiesis, and inflammatory responses. Cytokines have been classified into a number of families, including chemokines, hematopoietins, immunoglobulins, tumor necrosis factors, and a variety of unassigned molecules. *See generally Oxford Dictionary of Biochemistry and Molecular Biology*, Revised Edition, Oxford University Press, 2000; and C. A. Janeway, P. Travers, M. Walport and M. Schlomchik, *Immunobiology*, Fifth Edition, Garland Publishing, 2001 (hereinafter Janeway and Travers). A concise classification of cytokines is presented in Janeway and Travers, Appendix III, pages 677-679, the relevant disclosures of which are incorporated herein by reference.

Hematopoietins include, for example erythropoietin, interleukin-2 (IL-2, a 133 amino acid protein produced by T cells and involved in T cell proliferation), IL-3, IL-4, IL-5, IL-6, IL-7, IL-9, IL-11, IL-13, IL-15 (a 114 amino acid IL-2-like protein, which stimulates the growth of intestinal epithelium, T cells, and NK cells), granulocyte colony-stimulating factor (G-CSF), granulocyte-macrophage colony-stimulating factor (GM-CSF), oncostatin M (OSM), and leukemia inhibitory factor (LIF).

Interferons include, for example, IFN-α, IFN-β, and IFN-γ (a 143 amino acid homodimeric protein produced by T cells and NK cells, which is involved in macrophage activation, increased expression of MHC molecules and antigen processing components, IG class switching, and suppression of T_H2).

Immunoglobulins include, for example, B7.1 (CD80), and B7.2 (CD86), both of which co-stimulate T cell responses.

The tumor necrosis factor (TNF) family includes, for example, TNF-α, TNF-β (lymphotoxin), lymphotoxin-β (LT-β), CD40 ligand, Fas ligand, CD27 ligand, CD30 ligand, 4-1BB ligand, Trail, and OPG ligand.

Various cytokines that are not assigned to a particular family include, for example, tumor growth factor-β (TGF-β), IL-1α, IL-1β, IL-1 RA, IL-10, IL-12 (natural killer cell stimulatory factor; a heterodimer having a 197 amino acid chain and a 306 amino acid chain, which is involved in NK cell activation and induction of T cell differentiation to T_H1-like cells), macrophage inhibitory factor (MIF), IL-16, IL-17 (a cytokine production-inducing factor, which induces cytokine production in epithelia, endothelia, and fibroblasts), and IL-18.

Chemokines are a family of cytokines that are relatively small chemoattractant proteins and polypeptides, which stimulate the migration and activation of various cells, such as leucocyte migration (e.g., phagocytes and lymphocytes). Chemokines play a role in inflammation and other immune responses. Chemokines have been classified into a number of families, including the C chemokines, CC chemokines, CXC chemokines, and CX_3C chemokines. The names refer to the number and spacing of cysteine residues in the molecules; C chemokines having one cysteine, CC chemokines having two contiguous cysteines, CXC having two cysteines separated by a single amino acid residue, and CX_3C chemokines having two cysteines separated by three amino acid residues. Chemokines interact with a number of chemokine receptors present on cell surfaces. *See* Janeway and Travers, Appendix IV, page 680, the relevant disclosures of which are incorporated herein by reference.

In addition, chemokines can have immunomodulating activity and have been implicated in immune responses to cancer. For example, murine 6Ckine/SLC, the mouse analog of the human secondary lymphoid tissue chemokine (SLC), now commonly referred to as CCL21, has been reported to induce an antitumor response in a C-26 colon carcinoma tumor cell line. *See* Vicari, *et al. J. Immunol.* 2000; 165(4):1992-2000. Human CCL21 and its murine counterpart, 6Ckine/SLC, are classified as CC chemokines, which interact with the CCR7 chemokine receptor. Murine 6Ckine/SLC (muCCL21) is also reported by Vicari *et al.* to be a ligand for the CXCR3 chemokine receptor. Human CCL21, murine muCCL21 and a variety of other chemokines are implicated in the regulation of various immune system cells such as dendritic cells, T-cells, and natural killer (NK) cells.

Mig and IP-10 are CXC chemokines that interact with the CXCR3 receptor, which is associated with activated T cells. Lymphotactin is a C chemokine, which intereacts with the XCR1 receptor associated with T cells and NK cells. Fractalkine is a CX_3C chemokine, which interact with the CX_3CR1 receptor that is associated with T cells, monocytes and neutrophils.

NK cells are large granular lyphocytes that recognize and destroy cells that have been infected with a virus. NK cells can be regulated by interaction

of immunomodulating polypeptide ligands with receptors on the NK cell surface. For example, ligands for the NKG2D receptor that can regulate NK cell activity, include chemokines such as muCCL21, and stress-inducible polypeptide ligands such as MHC class I chain-related antigens and UL16 binding proteins. Murine H60 minor histocompatibility antigen peptide is reported to bind to the NKG2D receptor, as well. *See, e.g.,* Robertson *et al. Cell Immunol.* 2000; 199(1):8-14; Choi *et al. Immunity* 2002, 17(5):593-603, and Farag *et al.*, Blood, 2002; 100(6):1935-1947.

The present invention fulfills an ongoing need for vaccines that can stimulate a general immune response against cancer cells by providing a DNA vaccine encoding a cancer-associated IAP-family protein and an immunoactive gene product in a single vector.

SUMMARY OF THE INVENTION

A DNA vaccine effective for eliciting an immune response against cancer cells comprises a DNA construct operably encoding a cancer-associated IAP-family protein and an immunoactive gene product in a pharmaceutically acceptable carrier. Preferably, the DNA construct is operably incorporated in a vector such as an attenuated bacterium (e.g., an attenuated *Salmonella typhimurium* vector). The DNA vaccine includes a polynucleotide that encodes at least one cancer-associated IAP-family protein together with a polynucleotide that encodes an immunoactive gene product. Preferably the DNA construct encodes a cancer-associated IAP-family protein that is substantially absent from adult tissues, but which is elevated in cancer tissues, such as a survivin protein (e.g., a human survivin, murine survivin, and the like), or a livin protein. Preferably the immunoreactive gene product encoded by the DNA construct is a cytokine, a ligand for a natural killer cell surface receptor, or a similar immunoreactive molecule.

In one embodiment, the DNA vaccine preferably comprises a DNA that operably encodes a survivin protein selected from the group consisting of (a) wild-type human survivin having the amino acid residue sequence of SEQ ID NO: 2, (b) an immunogenic homolog of wild-type human survivin having an amino acid residue sequence at least 80% identical to SEQ ID NO: 2, (c) a splice variant of human survivin having the amino acid residue sequence of SEQ ID NO: 23, (d) a splice variant of human survivin having the amino acid residue sequence of SEQ ID

NO: 24, and (e) a fragment of a survivin protein that binds to a MHC class I molecule and is recognized by cytotoxic T cells.

In yet another embodiment, the DNA vaccine preferably comprises a DNA construct that operably encodes a livin protein selected from the group consisting of (a) full length wild-type human livin alpha splice variant having the amino acid residue sequence of SEQ ID NO: 27, (b) human livin beta splice variant having the amino acid residue sequence of SEQ ID NO: 29, (c) an immunogenic homolog of full length wild-type human livin having an amino acid residue sequence at least 80% identical to SEQ ID NO: 27, (d) an immunogenic homolog of wild-type human livin beta splice variant having an amino acid residue sequence at least 80% identical to SEQ ID NO: 29, and (e) a fragment of a livin protein that binds to a MHC class I molecule and is recognized by cytotoxic T cells.

Preferred cytokines include chemokines, such as human CCL21, murine CCL21, lymphotactin, fractalkine, IP-10, and the like, hematopoietins, such as IL-2, IL-15, and the like; interferons, such as IFN-γ and the like; as well as other cytokines associated with T cell and NK cell migration or proliferation, such as IL-12, IL-17 and the like.

Preferred natural killer cell surface receptor ligands are stress-inducible proteins such as human MICA, human MICB, human ULBP1, human ULBP2, human ULBP3, and the like, which bind to the NKG2D cell surface receptor. Particularly preferred NKG2D ligands are MICA and MICB.

Conventional adjuvants such as alum, oil-in-water emulsions, preservatives, and the like, can be present in the vaccines, as well. The DNA vaccines of the present invention stimulate an immune response against tumor cells, including stimulation of tumor cell apoptosis, thus inhibiting tumor growth and metastases.

In a method aspect of the present invention, a DNA vaccine is utilized to provide long term inhibition of tumor growth in a vaccinated patient. A DNA vaccine comprising a polynucleotide construct operably encoding a IAP-family protein and an immunoactive gene product in a pharmaceutically acceptable carrier is administered (preferably orally) to a patient in need of inhibition of tumor growth in an amount that is sufficient to elicit an immune response against tumor cells.

The vaccines of the present invention are useful for treatment of various types of cancers. For example, a patient suffering from a lung cancer, colorectal cancer, melanoma, and the like, can benefit from immunization by the vaccines of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the Drawings, FIG. 1 depicts the nucleic acid sequence encoding human survivin, SEQ ID NO: 1;

FIG. 2 depicts the amino acid residue sequence of human survivin, SEQ ID NO: 2;

FIG. 3 depicts the nucleic acid sequence encoding murine TIAP, SEQ ID NO: 3;

FIG. 4 depicts the amino acid residue sequence of murine TIAP, SEQ ID NO: 4;

FIG. 5 depicts the protein homology between human survivin and murine TIAP;

FIG. 6 depicts the nucleic acid sequence encoding human SLC (CCL21), SEQ ID NO: 5;

FIG. 7 depicts the amino acid residue sequence of human SLC (CCL21), SEQ ID NO: 6;

FIG. 8 depicts the nucleic acid sequence encoding murine6Ckine/SLC (muCCL21), SEQ ID NO: 7;

FIG. 9 depicts the amino acid residue sequence of murine 6Ckine/SLC (muCCL21), SEQ ID NO: 8;

FIG. 10 depicts the protein homology between human SLC (CCL21) and murine 6Ckine/SLC (muCCL21);

FIG. 11 depicts a partial nucleic acid sequence encoding murine minor histocompatibility antigen peptide H60, SEQ ID NO: 9;

FIG. 12 depicts a partial amino acid residue sequence of minor histocompatibility antigen peptide H60, SEQ ID NO: 10;

FIG. 13 is a schematic representation of DNA constructs encoding a survivin protein (murine survivin, also known as TIAP) and an immunomodulating chemokine (CCL21, also known as SLC) in a pBudCE4.1 vector;

FIG. 14A graphically depicts average tumor volume for pulmonary metastases of Lewis lung carcinomas in mice treated with a control buffer (E), a control vaccine comprising an empty vector (D), a DNA vaccine comprising a chemokine (C), a vaccine comprising a survivin protein (B) and a vaccine of the invention (A); FIG. 14B includes pictures of typical lung tumor metastases excised from the mice vaccinated as described in FIG.14A;

FIG. 15 depicts the T cell mediated cytotoxicity induced by the DNA vaccines described in FIG. 14A against D121 lung cancer cells; the percentage of lysis (Y-axis) is plotted for three different effector cell to target cell (E/T) ratios for each vaccination (i.e., 100:1, first data point; 50:1, second data point; and 25:1, third data point);

FIG. 16 graphically illustrates upregulated expression of T cell activation molecules in mice vaccinated with a vaccine of the invention as determined by flow cytometry analysis;

FIG. 17 graphically illustrates enhanced expression of co-stimulatory molecules by dendritic cells following vaccinations of mice with a vaccine of the invention and various control vaccines;

FIG. 18 illustrates induction of intracellular cytokine release following vaccinations of mice with a vaccine of the invention and various control vaccines, as determined by flow cytometry analysis;

FIG. 19 illustrates FACS plots demonstrating an increase in apoptosis in D121 lung tumor cells following vaccination of mice with the vaccine of the invention and various control vaccines (A) 3 hours after vaccination; and (B) 24 hours after vaccination;

FIG. 20 depicts a schematic representation of expression constructs incorporating TIAP and minor histocompatibility antigen peptide H60;

FIG. 21 graphically illustrates data from cytotoxicity assays of splenocytes isolated from mice vaccinated with a vaccine of the invention;

FIG. 22 depicts lungs excised from mice vaccinated as described in Example 10 (top) and a bar graph (bottom) of average lung weight of mice from the treatment groups;

FIG. 23 is a graph of the percentage survival of mice vaccinated and challenged with CT-26 tumor cells;

FIG. 24 illustrates expression of H60 peptide (A) and muSurvivin (B);

FIG. 25 illustrates the nucleic acid sequence encoding the CCL21b variant of 6CKine/SLC, SEQ ID NO: 11;

FIG. 26 illustrates the amino acid residue sequence of the CCL21b variant of 6CKine/SLC, SEQ ID NO: 12;

FIG. 27 illustrates the nucleic acid sequence encoding the human MICA, SEQ ID NO: 13;

FIG. 28 illustrates the amino acid residue sequence of the human MICA, SEQ ID NO: 14;

FIG. 29 illustrates the nucleic acid sequence encoding the human MICB, SEQ ID NO: 15;

FIG. 30 illustrates the amino acid residue sequence of the human MICB, SEQ ID NO: 16;

FIG. 31 illustrates the nucleic acid sequence encoding the human ULBP1, SEQ ID NO: 17;

FIG. 32 illustrates the amino acid residue sequence of the human ULBP1, SEQ ID NO: 18;

FIG. 33 illustrates the nucleic acid sequence encoding the human ULBP2, SEQ ID NO: 19;

FIG. 34 illustrates the amino acid residue sequence of the human ULBP2, SEQ ID NO: 20;

FIG. 35 illustrates the nucleic acid sequence encoding the human ULBP3, SEQ ID NO: 21;

FIG. 36 illustrates the amino acid residue sequence of the human ULBP3, SEQ ID NO: 22;

FIG. 37 illustrates the amino acid residue sequence of the human survivin splice variant survivin-2B (SEQ ID NO: 23) and splice variant survivin-ΔEx3 (SEQ ID NO:24);

FIG. 38 is reproduction of GENBANK record for Accession No. NP 005922, describing allelic variants of MICB;

FIG. 39 depicts the nucleic acid sequence encoding full length human livin alpha splice variant, SEQ ID NO: 26;

FIG. 40 depicts the amino acid residue sequence of human livin alpha splice variant, SEQ ID NO: 27;

FIG. 41 depicts the nucleic acid sequence encoding human livin beta splice variant, SEQ ID NO: 28; and

FIG. 42 depicts the amino acid residue sequence of human livin beta splice variant, SEQ ID NO: 29.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A DNA vaccine effective for eliciting an immune response against tumor cells comprises a DNA construct that operably encodes an IAP-family protein and an immunoactive gene product. The term "DNA construct" as used herein and in the appended claims means a synthetic DNA structure that can be transcribed in target cells. The construct can comprise a linear nucleic acid such as a purified DNA, a DNA incorporated in a plasmid vector, or a DNA incorporated into any other vector suitable for introducing DNA into a host cell. Preferably, the DNA is incorporated in a viral or bacterial vector, more preferably an attenuated viral or bacterial vector that is non-pathogenic, most preferably in an attenuated bacterial vector.

As used herein, the term "immunity" refers to long term immunological protection against the virulent form of the infectious agent or tumor antigen. The term "immunization" refers to prophylactic exposure to an antigen of a pathogenic agent derived from a non-virulent source, which results in immunity to the pathogen in the treated subject.

The term "antibody", as used herein, refers to a molecule that is a glycosylated protein, an immunoglobulin, which specifically binds to an antigen.

The term "antigen", as used herein, denotes an entity that, when introduced into an immunocompetent animal, stimulates production of specific antibody or antibodies that can combine with the antigen. The term "immunogen",

as used herein, denotes an entity that is not by itself able to stimulate antibody production but may do so if combined with a carrier.

The term "conservative substitution", as used herein, denotes replacement of one amino acid residue by another, biologically similar residue. Examples of conservative substitutions include the substitution of one hydrophobic residue such as isoleucine, valine, leucine or methionine for another, or the substitution of one hydrophilic residue such as arginine for lysine and vice versa, glutamic acid for aspartic acid vice versa, or glutamine for asparagine and vice versa, and the like.

The term "substantially corresponds" in its various grammatical forms as used herein relating to peptide sequences means a peptide sequence as described plus or minus up to three amino acid residues at either or both of the amino- and carboxy-termini and containing only conservative substitutions along the polypeptide sequence.

The term "immunoactive gene product" and grammatical variations thereof, as used herein and in the appended claims, includes proteins and polypeptides having an immunomodulating activity, such as proteins and polypeptides that interact with, and modulate the activity of T cells and NK cells.

The term "IAP-family protein" as used herein and in the appended claims includes any of the class of natural antigens expressed in tumor cells, which inhibit apoptosis in their natural form. IAP-family proteins include, for example, human survivin, human X chromosome-linked IAP (XIAP), murine TIAP (the murine analog of survivin), human livin, human c-IAP-1, human c-IAP-2., human NAIP, any other protein that includes at least one baculoviral inhibitor of apoptosis repeat (BIR) domain, or a homolog thereof. The BIR domain is present in all wild-type IAP-family proteins. It includes four relatively short alpha-helices and a region of three stranded anti-parallel beta sheet structure. The domain binds Zn using three cysteine residues and a histidine residue, which are conserved across IAP-family proteins. The term "IAP-family protein" as used herein and in the appended claims also includes variants of wild-type IAP proteins such as splice variants and substitution variants, and the like, as well as fragments and immunogenic homologs

thereof that bind to a major histocompatibility (MHC) class I molecule and are recognized by cytotoxic T-cells (i.e., survivin protein epitopes).

The term "cancer-associated" as used herein and in the appended claims, in reference to IAP-family proteins means an IAP-family protein that is expressed at elevated levels in cancer cells than it is in normal, non-cancerous cells. Examples of cancer-associated IAP-family proteins include, without limitation, human survivin and human livin.

The term "survivin protein" as used herein and in the appended claims includes the full length human survivin molecule (SEQ ID NO: 2), the full length murine analog thereof (i.e., TIAP, as described herein), variants of human survivin or murine survivin, such as splice variants and substitution variants, as well as fragments (e.g., epitopes) of human survivin and and immunogenic homologs of human survivin that bind to a major histocompatibility (MHC) class I molecule and are recognized by cytotoxic T cells. Known substitution variants of human survivin include a protein having the substitution T34A in the amino acid residue sequence of SEQ ID NO:2, a protein having the substitution D53A in the amino acid residue sequence of SEQ ID NO:2, and a protein having the substitution C84A in the amino acid residue sequence of SEQ ID NO:2 (*see* Song *et al.*, *Mol. Biol. Cell*, 2004; 15(3):1287-1296, E-publication December 29, 2003). Each of these known variants has apoptotic activity, in contrast to wild-type survivin which has anti-apototic activity.

In a preferred embodiment, the DNA vaccine of the present invention comprises a DNA construct that operably encodes a survivin protein such as wild-type human survivin having the amino acid residue sequence of SEQ ID NO: 2, an immunogenic homolog of wild-type human survivin having an amino acid residue sequence at least 80% identical to SEQ ID NO: 2, a splice variant of human survivin having the amino acid residue sequence of SEQ ID NO: 23, a splice variant of human survivin having the amino acid residue sequence of SEQ ID NO: 24, and a fragment of a survivin protein that binds to a MHC class I molecule and is recognized by cytotoxic T cells.

The term "livin protein" as used herein and in the appended claims includes the full length human livin alpha splice variant (SEQ ID NO: 27), the beta

splice variant of human livin (SEQ ID NO: 29), substitution variants of human livin alpha and beta splice variants, as well as fragments and immunogenic homologs thereof that bind to a MHC Class I molecule and are recognized by cytotoxic T-cells.

In another preferred embodiment, the DNA vaccine of the present invention comprises a DNA construct that operably encodes a livin protein such as full length wild-type human livin alpha splice variant having the amino acid residue sequence of SEQ ID NO: 27, human livin beta splice variant having the amino acid residue sequence of SEQ ID NO: 29, an immunogenic homolog of full length wild-type human livin having an amino acid residue sequence at least 80% identical to SEQ ID NO: 27, an immunogenic homolog of wild-type human livin beta splice variant having an amino acid residue sequence at least 80% identical to SEQ ID NO: 29, and a fragment of a livin protein that binds to a MHC class I molecule and is recognized by cytotoxic T cells.

As used herein and in the appended claims, the term "immunogenic homolog" and grammatical variations thereof, when used in reference to cancer-associated IAP-family proteins such as survivin and livin, means a protein having a high degree of homology to a wild-type cancer-associated IAP-family protein and which can bind to a MHC Class I molecule and can be recognized by cytotoxic T-cells that are active against the corresponding wild-type IAP family protein. Preferably the immunogenic homologs have an amino acid residue sequence that is at least about 80% identical to the amino acid sequence of the wild-type cancer-associated IAP-family protein, more preferably at least about 90% identical, most preferably at least about 95% identical.

Without being bound by theory, it is believed that vaccination of a patient, such as a human patient, with a vaccine of the invention leads to selective presentation of antigens derived from cancer-associated IAP-family protein on the surface of immune cells, such as antigen presenting cells, and in addition to the selective expression of the immunoactive gene product in these cells. Increased presentation of the cancer-associated IAP-family protein, such as a survivin protein or livin protein on the cell surface of the antigen presenting cell, in combination with expression of an immunoactive gene product, such as a cytokine or a ligand for a NK cell surface receptor, leads to an enhanced immune response against cancer cells that

express cancer-associated IAP-family proteins, such as a survivin protein or livin protein. In adult humans, survivin is expressed almost exclusively in cancer cells. Similarly, livin expression is reportedly elevated in some cancer cell lines, particularly melanoma cell lines.

In a preferred embodiment, the DNA vaccine comprises a polynucleotide sequence that operably encodes a survivin protein and a cytokine. Preferably, the survivin protein is human survivin, a murine survivin, or an epitope thereof. Preferably the cytokine modulates T cell or NK cell activity. Preferred cytokines include chemokines, hematopoietins, and interferons. Other preferred cytokines include NK cell activating cytokines such as IL-12 and cytokine production-stimulating factors such as IL-17.

In another preferred embodiment the DNA vaccine comprises a polynucleotide sequence that operably encodes a livin protein and a cytokine. Preferably the livin protein is wild-type human livin or an epitope thereof. Preferably the cytokine modulates T-cell or NK cell activity. Preferred cytokines include, chemokines, hematopoietins and interferons. Other preferred cytokines include NK cell activating cytokines such as IL-12 and cytokine production-stimulating factors such as IL-17.

Preferred chemokines include CC chemokines, particularly those which are ligands for the CCR7 chemokine receptor, such as CCL21 (SLC) and the like; C chemokines that are ligands for the CR1 receptor, such as lymphotactin, and the like; CX_3C chemokines that are ligands for the CX_3CR1 receptor, such as fractalkine, and the like; CXC chemokines, particularly those which are ligands for the CXCR3 receptor, such as IP-10 and the like. Most preferably the chemokine is human CCL21 or the murine analog thereof (murine CCL21).

Preferred hematopoietins include T cell growth factors such as IL-2, IL-15, and the like. Preferred interferons include those produced by T cells and NK cells such as IFN-γ, and the like. Other preferred cytokines include NK cell activating cytokines such as IL-12, and the like, and cytokines that induce cytokine production in cells such as epithelia, endothelia, and fibrolasts, including IL-17, and the like.

In another preferred embodiment, the DNA vaccine comprises a polynucleotide sequence that operably encodes a survivin protein and a ligand for a natural killer cell surface receptor. Preferably, the survivin protein is human survivin, murine survivin or an epitope of human survivin. Preferably the ligand for a natural killer cell surface receptor is a ligand for the NKG2D cell surface receptor. Preferably the ligand for the NKG2D cell surface receptor is a MHC class I chain-related (MIC) antigen such as MICA and MICB, a UL16 binding protein (ULBP) such as ULBP1, ULBP2, and ULBP3, and the like. Murine NKG2D ligands include, for example, Rae1 and minor histocompatibility antigen peptide H60. Most preferably, the ligand for the NKG2D cell surface receptor is MICA or MICB

In yet another preferred embodiment the DNA vaccine comprises a polynucleotide sequence that operably enclodes a livin protein and a ligand for a NK cell receptor. The livin protein can be wild-type human livin or an epitope of human livin or a livin variant.

Preferably, a DNA construct of the present invention, which operably encodes a cancer-associated IAP-family protein and an immunoactive gene product, is also operably linked to regulatory elements needed for gene expression, which are well known in the art.

Preferably the DNA construct is operably incorporated in an expression vector such as the BUDCE4.1 expression vector available from Invitrogen, Inc., Carlsbad, CA. Other suitable expression vectors are commercially available, for example, from BD Biosciences Clonetech, Palo Alto, CA. Once incorporated in the expression vector, the DNA construct can be introduced into a host vector such as a live, attenuated bacterial vector by transfecting the host cell with the expression vector to provide a vaccine of the present invention.

DNA constructs preferably include regulatory elements necessary for expression of nucleotides. Such elements include, for example, a promoter, an initiation codon, a stop codon, and a polyadenylation signal. In addition, enhancers are often required for expression of a sequence that encodes an immunogenic target protein. As is known in the art, these elements are preferably operably linked to the

sequence that encodes the desired protein. Regulatory elements are preferably selected that are compatible with the species to which they are to be administered.

Initiation codons and stop codons are preferably included as part of a nucleotide sequence that encodes the survivin protein and the immunomodulating polypeptide in a genetic vaccine of the present invention. The initiation and termination codons must, of course, be in frame with the coding sequences for the survivin protein and the immunomodulating polypeptide.

Promoters and polyadenylation signals included in a vaccine of the present invention are preferably selected to be functional within the cells of the subject to be immunized.

Examples of promoters useful in the vaccines of the present invention, especially in the production of a genetic vaccine for humans, include but are not limited to promoters from Simian Virus 40 (SV40), Mouse Mammary Tumor Virus (MMTV) promoter, Human Immunodeficiency Virus (HIV) such as the HIV Long Terminal Repeat (LTR) promoter, Moloney virus, Cytomegalovirus (CMV) such as the CMV immediate early promoter, Epstein Barr Virus (EBV), Rous Sarcoma Virus (RSV) as well as promoters from human genes such as human actin, human myosin, human hemoglobin, human muscle creatine, and human metalothionein.

Examples of polyadenylation signals useful in the vaccines of the present invention, especially in the production of a genetic vaccine for humans, include but are not limited to SV40 polyadenylation signals and LTR polyadenylation signals.

In addition to the regulatory elements required for DNA expression, other elements can also be included in the DNA molecule. Such additional elements include enhancers. The enhancer can be, for example, human actin, human myosin, human hemoglobin, human muscle creatine and viral enhancers such as those from CMV, RSV and EBV.

Regulatory sequences and codons are generally species dependent. In order to maximize protein production, the regulatory sequences and codons are selected to be effective in the species to be immunized. One having ordinary skill in

the art can readily produce DNA constructs that are functional in a given subject species.

The DNA constructs of the present vaccines can be "naked" DNA as defined in Restifo *et al. Gene Therapy* 2000; 7:89-92, the pertinent disclosure of which is incorporated by reference. Preferably, the DNA is operably incorporated in a vector. Useful delivery vectors include biodegradable microcapsules, immuno-stimulating complexes (ISCOMs) or liposomes, and genetically engineered attenuated live vectors such as viruses or bacteria.

Examples of suitable attenuated live bacterial vectors include *Salmonella typhimurium*, *Salmonella typhi*, *Shigella* species, *Bacillus* species, *Lactobacillus* species, *Bacille Calmette-Guerin (BCG)*, *Escherichia coli*, *Vibrio cholerae*, *Campylobacter* species, *Listeria* species, or any other suitable bacterial vector, as is known in the art. Preferably the vector is an attenuated live *Salmonella typhimurium* vector. Preferred attenuated live *Salmonella typhimurium* include *AroA* $^-$ strains such as SL7207, or doubly attenuated *AroA* $^-$, *dam* $^-$ strains, such as RE88. The doubly attenuated *AroA* $^-$, *dam* $^-$ *Salmonella typhimurium* is a particularly preferred vector.

Methods of transforming live bacterial vectors with an exogenous DNA construct are well described in the art. See, for example, Joseph Sambrook and David W. Russell, *Molecular Cloning, A Laboratory Manual*, 3rd Ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York (2001) (Sambrook and Russell).

Preferred viral vectors include Bacteriophages, Herpes virus, Adenovirus, Polio virus, Vaccinia virus, and Avipox. Methods of transforming viral vector with an exogenous DNA construct are also well described in the art. *See* Sambrook and Russell, above.

Useful liposome vectors are unilamellar or multilamellar vesicles, having a membrane portion formed of lipophilic material and an interior aqueous portion. The aqueous portion is used in the present invention to contain the polynucleotide material to be delivered to the target cell. It is generally preferred that the liposome forming materials have a cationic group, such as a quaternary ammonium group, and one or more lipophilic groups, such as saturated or

unsaturated alkyl groups having about 6 to about 30 carbon atoms. One group of suitable materials is described in European Patent Publication No. 0187702, and further discussed in U.S. Patent No. 6,228,844 to Wolff *et al.*, the pertinent disclosures of which are incorporated by reference. Many other suitable liposome-forming cationic lipid compounds are described in the literature. See, e.g., L. Stamatatos, *et al.*, *Biochemistry* 1988; 27:3917-3925; and H. Eibl, *et al.*, *Biophysical Chemistry* 1979; 10:261-271. Alternatively, a microsphere such as a polylactide-coglycolide biodegradable microsphere can be utilized. A nucleic acid construct is encapsulated or otherwise complexed with the liposome or microsphere for delivery of the nucleic acid to a tissue, as is known in the art.

Other useful vectors include polymeric microspheres comprising biodegradable poly(ortho ester) materials, as described by Wang *et al.*, *Nat. Mater.*, 2004; 3(3):190-6. Epub 2004 Feb. 15, the relevant disclosures of which are incorporated herein by reference.

A method aspect of the present invention involves administering DNA vaccine operably encoding a cancer-associated IAP-family protein and an immunoreactive gene product to the tissue of a mammal, such as a human. In some preferred embodiments, the DNA vaccines are administered orally, intramuscularly, intranasally, intraperitoneally, subcutaneously, intradermally, or topically. Preferably the DNA vaccine is administered orally.

In a preferred method, a DNA vaccine of the present invention can be utilized to provide long term inhibition of tumor growth in a patient treated with the vaccine. The DNA vaccine comprises a DNA polynucleotide construct operably encoding a cancer-associated IAP-family protein such as a survivin protein, an immunoactive gene product such as a cytokine or a ligand for a NK cell surface receptor, and a pharmaceutically acceptable carrier therefor. The vaccine is administered to a mammal in need of inhibition tumor growth in an amount that is sufficient to elicit an immune response against tumor cells.

Preferably, the mammal treated with a vaccine of the invention is a human. A patient suffering from cancer, such as lung or colon carcinoma, breast tumors, or prostate tumors, and the like cancers, can benefit from immunization by the vaccines of the present invention.

Vaccines of the present invention preferably are formulated with pharmaceutically acceptable carriers or excipients such as water, saline, dextrose, glycerol, and the like, as well as combinations thereof. The vaccines can also contain auxiliary substances such as wetting agents, emulsifying agents, buffers, preservatives, adjuvants, and the like.

The vaccines of the present invention are preferably administered orally to a mammal, such as a human, as a solution or suspension in a pharmaceutically acceptable carrier, at a DNA concentration in the range of about 1 to about 10 micrograms per milliliter. The appropriate dosage will depend upon the subject to be vaccinated, and in part upon the judgment of the medical practitioner administering or requesting administration of the vaccine.

The vaccines of the present invention can be packaged in suitably sterilized containers such as ampules, bottles, or vials, either in multi-dose or in unit dosage forms. The containers are preferably hermetically sealed after being filled with a vaccine preparation. Preferably, the vaccines are packaged in a container having a label affixed thereto, which label identifies the vaccine, and bears a notice in a form prescribed by a government agency such as the United States Food and Drug Administration reflecting approval of the vaccine under appropriate laws, dosage information, and the like. The label preferably contains information about the vaccine that is useful to an health care professional administering the vaccine to a patient. The package also preferably contains printed informational materials relating to the administration of the vaccine, instructions, indications, and any necessary required warnings.

The human survivin DNA sequence and its corresponding protein sequence have been reported by Strausberg in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, DNA Accession No. BC034148, the disclosures of which are incorporated herein by reference. The DNA sequence and corresponding protein sequence of murine TIAP have been reported by Kobayashi *et al. Proc. Natl. Acad. Sci.* 1999; 96:1457-62; DNA Accession No. AB01389 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton,

Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference.

The nucleic acid sequence encoding human survivin is presented in FIG. 1 (SEQ ID NO: 1), and its corresponding amino acid residue sequence (SEQ ID NO: 2) is provided in FIG. 2. The nucleic acid sequence encoding murine survivin (i.e., TIAP) is presented in FIG. 3 (SEQ ID NO: 3), and its corresponding amino acid residue sequence (SEQ ID NO: 4) is provided in FIG. 4.

The protein homology between human survivin and its murine counterpart, TIAP, is illustrated in FIG. 5. There is about 83% amino acid residue sequence identity between human survivin (SEQ ID NO: 2) and murine TIAP (SEQ ID NO: 4) as shown in FIG. 5.

Mahotka *et al.* have identified two splice variants of human survivin, designated survivin-ΔEx3 and survivin-2B, which are also suitable for use in the present invention. Mahotka *et al. Cancer Res.*,1999; 59:6097-6102, the relevant disclosures of which are incorporated herein by reference. The amino acid residue sequences of survivin-2B (SEQ ID NO: 23) and survivin-ΔEx3 (SEQ ID NO:24) are shown in FIG. 37. Hirohashi *et al.* have identified a potent T cell epitope from survivin-2B, having the amino acid residue sequence AYACNTSTL (SEQ ID NO: 25), designated survivin-2B80-88, which elicits a cytotoxic T lymphocyte response against survivin-2B. Hirohashi *et al. Clinical Cancer Res.*, 2002; 8:1731-39, the relevant disclosures of which is incorporated herein by reference. This epitope is a fragment of survivin which is capable of binding with a MHC class I molecule and is recognized by cytotoxic T cells, and is suitable for use as the IAP-family protein component of a vaccine of the present invention.

Another splice variant of human survivin is the survivin-3B variant described by Badran *et al.*, *Biochem. Biophys. Res. Commun.*, 2004; 314(3):902-907. The polynucleotide sequence encoding survivin-3B and its corresponding amino acid residue sequence are reported in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, DNA Accession No. AB154416, the disclosures of which are incorporated herein by reference.

Full length human livin (known as the alpha variant) is an IAP-family protein having a single BIR domain and consisting of 298 amino acid residues. The DNA sequence and corresponding protein sequence of human livin alpha variant have been reported by Clark *et al.* in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, DNA Accession No. NM 139317, the disclosures of which are incorporated herein by reference. The DNA sequence and corresponding protein sequence of the beta variant of human livin have been reported by; Accession No. NM 022161 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference.

The nucleic acid sequence encoding full length human livin (alpha variant) is presented in FIG. 39 (SEQ ID NO: 26), and its corresponding amino acid residue sequence (SEQ ID NO: 27) is provided in FIG. 40. The nucleic acid sequence encoding the beta variant of human livin is presented in FIG. 41 (SEQ ID NO: 28), and its corresponding amino acid residue sequence (SEQ ID NO: 29) is provided in FIG. 42. The beta variant of human livin lacks amino acid residues 216 through 233 of the full length human livin alpha splice variant (SEQ ID NO: 27). The beta variant is identical to the alpha variant of human livin in all other respects. The BIR domain of both the alpha and beta variants of human livin is in the region from amino acid residue R90 to amino acid residue L155 of SEQ ID NO: 27 and SEQ ID NO: 29).

In a preferred embodiment, the vaccines for the present invention comprise DNA constructs that encode one or more survivin proteins, such as human survivin, TIAP (murine survivin), and immunogenic homologs thereof. The immunogenic homologs preferably share at least about 80% amino acid residue sequence identity with human survivin, more preferably at least about 90% amino acid residue sequence identity, most preferably at least about 95% amino acid residue sequence identity with SEQ ID NO: 2. Alternatively, the vaccine can comprise a DNA construct that encodes one or more T-cell epitopes of human survivin protein.

In another preferred embodiment, the vaccines for the present invention comprise DNA constructs that encode one or more livin proteins, such as human livin alpha and beta splice variants (SEQ ID NO: 27 and 29, respectively), immunogenic homologs thereof. The immunogenic homologs preferably share at least about 80% amino acid residue sequence identity with the alpha or beta spice variant of human livin, more preferably at least about 90% amino acid residue sequence identity, most preferably at least about 95% amino acid residue sequence identity with SEQ ID NO: 27 or SEQ ID NO: 29. Alternatively, the vaccine can comprise a DNA construct that encodes one or more T-cell epitopes of a human livin protein.

Due to the inherent degeneracy of the genetic code, DNA sequences that encode substantially the same or a functionally equivalent amino acid residue sequence to native (i.e., naturally occurring) cancer-associated IAP-family proteins, such as human survivin, murine survivin, and human livin splice variants, can be used in the vaccines of the invention. Such DNA sequences include those which are capable of hybridizing to the native survivin or livin DNA sequences, as well as allelic variants, and the like. Preferably the DNA of the functionally equivalent homologs share at least about 70% nucleotide sequence identity with the DNA encoding the aforementioned native survivin or livin proteins, more preferably at least about 80% nucleotide sequence identity.

Immunoactive gene products encoded by the DNA constructs of the present vaccines are preferably cytokines or ligands of natural killer cell surface receptors. Particularly preferred cytokines are CC chemokines. Particularly useful CC chemokines are ligands for the CCR7 chemokine receptor. Selective CCR7 ligands include CCL19 (also known as exodus-3, ELC, MIP-3β and CKβ11) and CCL21 (also known as exodus-2, SLC, 6Ckine, TCA4 and CKβ9). Particularly preferred chemokines are human CCL21 and its murine counterpart 6Ckine/SLC (muCCL21), and chemokines substantially corresponding thereto.

DNA and protein sequences for human SLC have been reported by Nishimura *et al.*, in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, DNA Accession No. AB002409, the disclosures of which are incorporated herein by

reference. The murine CCL21a variant of 6Ckine/SLC DNA and protein sequences have been reported by Hromas *et al. J. Immunol.* 1997; 159(6):2554-2558, DNA Accession No. NM011335 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which is incorporated herein by reference. The murine CCL21b variant of 6Ckine/SLC DNA and protein sequences have been reported by Hedrick *et al., J. Immunol.* 1997;159(4):1589-1593, DNA Accession No. NM011124 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which is incorporated herein by reference.

The nucleic acid sequence encoding human CCL21 (SLC) is presented in FIG. 6 (SEQ ID NO: 5), and its corresponding amino acid residue sequence (SEQ ID NO: 6) is provided in FIG. 7. The nucleic acid sequence encoding murine CCL21 (CCL21b variant) is presented in FIG. 8 (SEQ ID NO: 7), and its corresponding amino sequence (SEQ ID NO: 8) is provided in FIG. 9.

The protein homology between human CCL21 (SLC) and its murine counterpart (murine 6Ckine/SLC, CCL21b) is illustrated in FIG. 10. There is about 73% amino acid residue sequence identity between human CCL21 (SEQ ID NO: 6) and murine CCL21 (SEQ ID NO: 8) as shown in FIG. 10.

The nucleic acid sequence encoding the CCL21a variant of murine SLC is presented in FIG. 25 (SEQ ID NO: 11), and its corresponding amino sequence (SEQ ID NO: 12) is provided in FIG. 26.

Preferred ligands for natural killer cell surface receptors are ligands for the murine NKG2D surface receptor. Preferred ligands for the NKG2D surface receptor are MICA, MICB, ULBP1, ULBP2, and ULBP3, and the like. Most preferably MICA and MICB. Other known ligands for NKG2D surface receptors include murine Rea-1β and murine minor histocompatibility antigen peptide H60.

The murine H60 minor histocompatibility antigen peptide DNA and protein sequences have been reported by Malarkannan *et al., J. Immunol.* 1998; 161(7):3501-3509, DNA Accession No. AF084643 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by

reference. A partial nucleic acid sequence encoding murine H60 minor histocompatibility antigen peptide is presented in FIG. 11 (SEQ ID NO: 9), and its corresponding partial amino acid residue sequence (SEQ ID NO: 10) is provided in FIG. 12.

DNA and protein sequences for human MICA have been reported by Zwirner *et al.*, DNA Accession No. AY204547 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference. The nucleic acid sequence encoding human MICA is presented in FIG. 27 (SEQ ID NO: 13), and its corresponding amino acid residue sequence (SEQ ID NO: 14) is provided in FIG. 28.

DNA and protein sequences for human MICB have been reported by Bahram *et al. Immunogenetics* 1996; 45(2):161-162, DNA Accession No. U65416 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference. The nucleic acid sequence encoding human MICB is presented in FIG. 29 (SEQ ID NO: 15), and its corresponding amino acid residue sequence (SEQ ID NO: 16) is provided in FIG. 30. Allelic variants of MICB are described in GENBANK Accession No. NP 005922, incorporated herein by reference. FIG. 38 is a reproduction of the GENBANK entry for Accession No. NP 005922.

DNA and protein sequences for human ULBPI have been reported by Cosman *et al., Immunity* 2001; 14(2):123-133, DNA Accession No. AF304377 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference. The nucleic acid sequence encoding human ULBP1 is presented in FIG. 31 (SEQ ID NO: 17), and its corresponding amino acid residue sequence (SEQ ID NO: 18) is provided in FIG. 32.

DNA and protein sequences for human ULBP2 have been reported by Cosman *et al., Immunity* 2001; 14(2):123-133, DNA Accession No. AF304378 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are

incorporated herein by reference. The nucleic acid sequence encoding human ULBP2 is presented in FIG. 33 (SEQ ID NO: 19), and its corresponding amino acid residue sequence (SEQ ID NO: 20) is provided in FIG. 34.

DNA and protein sequences for ULBP3 have been reported by Cosman *et al., Immunity* 2001; 14(2):123-133, DNA Accession No. AF304379 in the *EMBL* database of the European Bioinformatics Institute, Wellcome Trust Genome Campus, Hinxton, Cambridge CB10 1SD, UK, the disclosures of which are incorporated herein by reference. The nucleic acid sequence encoding human ULBP3 is presented in FIG. 35 (SEQ ID NO: 21), and its corresponding amino acid residue sequence (SEQ ID NO: 22) is provided in FIG. 36.

Particularly preferred natural killer cell surface receptor ligands include ligands for the NKG2D receptor such as MICA, MICB, ULBP1, ULBP2, ULBP3, and functional equivalents thereof. The functional equivalents preferably share at least about 80 % amino acid residue sequence identity with the aforementioned immunomodulating polypeptides, more preferably at least about 90% amino acid residue sequence identity, most preferably at least about 95% amino acid residue sequence identity.

Due to the inherent degeneracy of the genetic code, DNA sequences that encode substantially the same or a functionally equivalent amino acid residue sequence to the useful native immunoactive gene products such as human CCL21, murine CCL21, MICA, MICB, ULBP1, ULBP2, ULBP3, and like materials substantially corresponding thereto can be used in the vaccines of the invention. Such DNA sequences include those which are capable of hybridizing to the immunomodulating polypeptide DNA sequences, as well as allelic variants, and the like. Preferably the DNA of functionally equivalent homologs share at least about 70 % nucleotide sequence identity with the DNA encoding the aforementioned native immunomodulating polypeptides.

Altered DNA sequences that can be used in accordance with the invention include deletions, additions or substitutions of different nucleotide residues in the native polynucleotide sequence encoding a wild-type cancer-associated IAP-family protein resulting in a sequence that encodes the wild-type protein or an immunogenic homolog thereof. The altered DNA sequences that can

be used in accordance with the invention can also include deletions, additions or substitutions of different nucleotide residues in the native polynucleotide encoding a wild type immunogenic gene product resulting in a sequence that encodes the wild-type immunoactive gene product or a functional equivalent thereof. Functionally equivalent immunoactive gene product may contain deletions, additions or substitutions of amino acid residues within a wild-type cytokine, or NK cell surface receptor ligand, which result in a silent change, thus producing a functionally equivalent molecule. Such amino acid substitutions (e.g., conservative substitutions) may be made on the basis of similarity in polarity, charge, solubility, hydrophobicity, hydrophilicity, and/or the amphipathic nature of the residues involved. For example, negatively charged amino acids include aspartic acid and glutamic acid; positively charged amino acids include lysine and arginine; amino acids with uncharged polar head groups having similar hydrophilicity values include the following: leucine, isoleucine, valine; glycine, alanine; asparagine, glutamine; serine, threonine; phenylalanine, tyrosine.

As used herein, a functionally equivalent immunoactive gene product, such as a cytokine or NK cell surface receptor ligand refers to a polypeptide having substantially the same immunomodulating activity as its counterpart naturally occurring immunoactive gene product.

The DNA sequences operably encoding the IAP-family protein and the immunoactive gene products useful in the vaccines of the invention may be engineered to alter the coding sequences for a variety of purposes including, but not limited to, alterations that modify processing and expression of the gene product. For example, mutations may be introduced using techniques that are well known in the art, e.g. site-directed mutagenesis, to insert new restriction sites, to alter glycosylation patterns, phosphorylation, and the like.

Another aspect of the present invention is a method of vaccinating a mammal against cancer. The method comprises administering to the mammal a vaccine of the present invention, as described herein, in an amount sufficient to elicit an immune response against cancer cells. Preferably the mammal is a human.

In another aspect, the present invention also encompasses transformed host cells, which have been transfected with a vector comprising a DNA

construct operably encoding an Inhibitor of Apoptosis-family protein and an immunoactive gene product, as described herein. The host cell can be a prokaryotic cell or a eukaryotic cell.

The present invention also provides isolated plasmid vectors comprising a DNA construct operably encoding an Inhibitor of Apoptosis-family protein and an immunoactive gene product. The vectors are useful for transfecting host cells, such as attenuated bacterial cells, for preparing the vaccines of the invention.

The following examples are provided to further illustrate the features and embodiments of the present invention, and are not meant to be limiting.

Materials, Methods and Examples.

Materials. C57/BL/6J and Balb/C mice were obtained from the Scripps Research Institute breeding facility. The DNA encoding TIAP (the murine form of survivin) was cloned by PCR from MC3P cDNA. The DNA encoding murine 6Ckine (murine CCL21) was cloned from spleen cells. DNA encoding H60 minor histocompatibility antigen peptide (the murine form of MICA and MICB) was kindly provided by Dr. David H. Ranlet of the University of California (Berkley). The DNA for the vaccine encoding murine CCL21 (muCCL21, also known as 6Ckine/SLC) and murine survivin (muSurvivin, also known as TIAP) was cloned into pBudCE4.1 eucaryotic expression vectors from Invitrogen, Inc., using the restriction sites HindIII and BamHI for MuCCL21, and using XhoI for both ends of muSurvivin. The DNA for the vaccine encoding H60 and TIAP was cloned into pBudCE4.1 eucaryotic expression vectors from Invitrogen, Inc., using the restriction sites HindIII and XbaI for H60, and for muSurvivin, using the restriction sites KpnI and XhoI. An *AroA* $^{-}$ attenuated strain of *Salmonella typhimurium* (SL2707) and a doubly attenuated *AroA* $^{-}$, *dam* $^{-}$ strain of *Salmonella typhimurium* (RE88) were obtained from Remedyne, Santa Barbara, CA. Antibodies were obtained from BD Biosciences, Bedford, MA. Fluorescein isothiocyanate (FITC) and R-Phycoerythrin (PE) were obtained from Molecular Probes, Eugene, OR. FITC-labeled and PE-labeled antibodies were prepared according to the manufacturer's recommended protocols.

Part A. Vaccines From Tranformed *AroA* $^-$ Attenuated *Salmonella typhimurium*.

EXAMPLE 1. Preparation of a DNA Vaccine Encoding muSurvivin and muCCL21.

The pBudCE4.1 vector containing muSurvivin and muCCL21 DNA (about 1-10 μg of pDNA) was electroporated into freshly prepared attenuated *Salmonella typhimurium* (SL2707), utilizing a Bio-Rad Pulser at 2.5 kV, 25 μF, and 200 Ohm according to the manufacturer's recommended procedures. *Salmonella* containing the vector were selected on zeocin-containing plates. Colonies were picked the next day and cultured overnight in LB broth (EM Science, Gibbstown, NJ) with zeocin added. The bacteria were isolated and washed in phosphate buffered saline (PBS). The washed bacteria were then suspended in PBS medium at a concentration of about $1x10^9$ recombinant *Salmonella* per milliliter of PBS, to form a vaccine solution for later use.

Control vaccines consisting of *Salmonella* transformed with the vector alone, a vector incorporating only muSurvivin DNA, and a vector incorporating only muCCL21 DNA were also prepared according to the same procedure. FIG. 13 provides a schematic representation of the expression constructs.

The vaccines were stored in sealed ampules until used. The plasmid DNA was stored at about -80 °C before transforming the *Salmonella*.

EXAMPLE 2. Vaccination of Mice with DNA Vaccines of Example 1.

Balb/C mice (about 8 mice per treatment group) were vaccinated with the DNA vaccines of Example 1 (about $1x10^8$ recombinant *Salmonella* in about 100 μl of PBS) by oral gavage, 3 times at 2 week intervals.

EXAMPLE 3. Evaluation of Tumor Resistance of Vaccinated Mice.

About 1 week after the last vaccination, Balb/C mice from Example 2 (about 8 mice per treatment group) were challenged with about $1x10^5$ D121 Lewis lung carcinoma cells (subcutaneously). The subcutaneous Lewis lung tumors were surgically removed after about 2 weeks of growth to allow spontaneous

dissemination to the lung. Subcutaneous tumor growth was measured in two dimensions every other day, and tumor volume was calculated according to the formula:

$$\text{volume} = (\text{width}^2)(\text{length} \div 2)$$

for each tumor. The amount of spontaneous metastasis of D121 to the lungs was evaluated about 24 to about 28 days after removal of the subcutaneous primary tumor. The mice were sacrificed and necropsied, and the tumor burdens of the lungs were evaluated according to the percentage of the lung surface that was covered by tumor and scored as "0" for no tumor, "1" for less than about 20% tumor coverage, "2" for about 20 to about 30% tumor coverage, and "3" for greater than about 50% tumor coverage.

The tumor burden scores for the mice vaccinated with the vaccines of Example 1 are provided in Table 1. FIG. 14 shows pictures of lungs from mice vaccinated with the vaccines of Example 1. Tumor volumes are reported in Table 1 and in FIG. 14. In FIG. 14, bar A represents the average lung tumor volume (in cubic millimeters) for mice vaccinated with the muSurvivin/muCCL21 vaccine of the invention; bar B represents the average tumor volume for mice vaccinated with the vaccine that only incorporated muSurvivin DNA; bar C represents the average tumor volume for mice vaccinated with the vaccine that only incorporated muCCL21 DNA; bar D represents the average tumor volume for mice vaccinated with the vaccine that only incorporated the empty vector; and bar E represents the average tumor volume for mice vaccinated with PBS buffer. FIG. 14 also includes pictures of representative excised lungs from each treatment group, shown below each of their respective bars from FIG. 14.

Table 1. Tumor Metastasis in Balb/C Mice Challenged with D121 Lewis Lung Carcinoma Cells.

Mouse Vaccination Group	Metastatic Scores
A. muSurvivin/muCCL21 Vaccine average lung tumor volume:	0,0,0,1,1,1,2,2 (0.242 ± 0.06 mm^3)
B. Control - muSurvivin Vaccine average lung tumor volume:	1,1,2,3,3,3,3,3 (0.483 ± 0.10 mm^3)
C. Control - muCCL21 vaccine average lung tumor volume:	2,2,2,3,3,3,3,3 (0.626 ± 0.06 mm^3)
D. Control - empty vector vaccine average lung tumor volume:	2,3,3,3,3,3,3,3 (1.152 ± 0.24 mm^3)
E. Control - vaccination with PBS average lung tumor volume:	2,3,3,3,3,3,3,3 (1.212 ± 0.35 mm^3)

The results provided in Table 1 and FIG. 14 (diagrams A and B) demonstrate that the DNA vaccine comprising a DNA construct encoding an IAP-family protein (i.e., muSurvivin) and an immunoactive gene product (i.e., muCCL21) can effectively immunize mice against lung tumor metastases and inhibited growth of lung tumors.

EXAMPLE 4. T Cell Mediated Cytotoxicity Against D121 Lung Cancer Cells Induced by DNA Vaccine of the Invention of the Invention.

C5/7BL/6J mice (about 8 mice per treatment group) were vaccinated with the DNA vaccines of Example 1 as described in Example 2. Splenocytes were isolated about 4 days after vaccination and analyzed for their lytic activity in a 4-hour ^{51}Cr-release assay, as described in *Current Protocols in Immunology* at 3.11.4, Coligan, *et al.* Eds., John Wiley & Sons, Inc. (1994). D121 cells were used as target cells for the splenocytes.

FIG. 15 graphically illustrates T cell mediated cytotoxicity against D121 lung cancer cells induced by the DNA vaccines of the invention. The data points represented by the open circles represent data from inhibition assays wherein

the cells were treated with 50 μg/ml of antibodies to H-2K^b/H-2D^b MHC class I antigens (clone SF1-1.1; 34-2-12 IgG2a, κ) and the solid black squares represent data in the absence of inhibiting antibodies. The percentage of lysis of tumor cells (Y-axis) is plotted for three different effector cell to target cell (E/T) ratios for each vaccination group (i.e., E/T of 100:1 for the first data point; 50:1 for the second data point; and 25:1 for the third data point). The results demonstrate that the muSurvivin/muCCL21vaccine of the invention (labeled SLC/TIAP) induced almost a 5-fold increase in lysis at the 100:1 E/T ratio compared to control vaccines comprising PBS, empty vector, and muCCL21 DNA, and an increase of about 2-fold over the control vaccine comprising muSurvivin DNA alone.

EXAMPLE 5. Upregulation of CD25, CD69 and CD28 Activation Markers in Splenocytes (CD8+ T Cells) From Vaccinated Mice.

C5/7BL/6J mice (about 4 mice per treatment group) were vaccinated with the DNA vaccines of Example 1 as described in Example 2. Splenocytes were isolated from the immunized mice and the control mouse group about 1 week after the last vaccination. The cells were then stained with FITC-conjugated CD8+ antibody and PE-conjugated antibodies of CD25, CD69, and CD28. The cell suspensions were evaluated using a two color flow cytometry Becton Dickenson FAC scan to determine the percentage of CD8+T cells positive for CD25, CD 28 and CD69 for each splenocyte. The results are presented in FIG. 16. The numerical value in the upper right hand quadrant in each FACS plot indicates the percentage of cells that presented both CD8+ antigen as well as CD25, CD28, or CD69, as the case may be. The numerical results are shown in Table 2. These results demonstrate increased T cell marker expression with the vaccine of the present invention, indicating enhanced T cell activation.

Table 2. Upregulation of CD25, CD69 and CD28 Activation Markers in Splenocytes From Vaccinated Mice

Treatment	% CD25 and DC8+	% CD69 and DC8+	% CD28 and DC8+
Control vaccine/PBS	7.3	11.2	1.62
Control vaccine/empty vector	8.2	11.4	1.57
Control vaccine/muCCL21	10.2	12.9	2.3
Control vaccine/muSurvivin	9.5	13.3	2.21
muSurvivin/muCCL21 vaccine	12.4	17.7	3.8

The data in Table 2 and FIG 16 demonstrate that the inventive vaccine of Example 1, comprising a DNA construct encoding for muSurvivin and muCCL21 leads to upregulated expression of T cell activation molecules.

EXAMPLE 6. Enhanced Expression of Co-Stimulatory Molecules on Dendritic Cells in Vaccinated Mice.

C5/7BL/6J mice (about 4 mice per treatment group) were vaccinated with the DNA vaccines of Example 1 as described in Example 2. Splenocytes were isolated from the immunized mice and the control mouse group about 1 week after the last vaccination. The cells were then stained with FITC-conjugated CD11c antibody in combination with PE-conjugated antibodies of co-stimulatory molecules B7 (CD80), ICAM-1, and DEC205. The cell suspensions were evaluated using a two color flow cytometry Becton Dickenson FAC scan. FIG. 17 graphically illustrates the mean fluorescence values for the cells showing increased expression of ICAM-1 (top), CD80 (middle) and DEC205 (bottom) for splenocytes isolated from mice vaccinated with a the muSurvivin/muCCL21 vaccine of the invention, relative to the control vaccines.

EXAMPLE 7. Induction of Intracellular Cytokine Release.

Mice immunized as in Example 2 (8 mice per group) were challenged with D121 Lung Cancer Cells as in Example 3. Splenocytes were harvested from each mouse about one week after tumor cell challenge. The splenocytes were stained with FITC-anti-CD3 antibody and then fixed, permeabilized, and subsequently stained with PE conjugated anti IFN-γ antibody. The two-color stained cells were analyzed by FACS flow cytometry. The results are illustrated in FIG. 18. The cells were fixed using an intracellular staining starter kit from BD Pharmingen, La Jolla, CA.

The results plotted in FIG. 18 demonstrate that the percentage of cells releasing the cytokine IFN-γ increased to about 3.17 % for splenocytes isolated from mice vaccinated with a vaccine of the invention, compared to only 0.41% for mice receiving the PBS control vaccine, about 0.38 % for mice receiving the empty vector control vaccine, about 0.96 % for mice receiving the SLC control vaccine and about 1.53 % for mice receiving the muSurvivin control vaccine.

EXAMPLE 8. Enhanced Apoptosis of Lung Cancers Cell in Vaccinated Mice.

Mice immunized as in Example 2 (8 mice per group) were challenged with D121 Lung Cancer Cells as in Example 3. Splenocytes were harvested from each mouse about one week after tumor cell challenge. The splenocytes were incubated with D121 tumor cells at a temperature of about 37 °C, for about 3 hours. Tumor cells were then isolated and analyzed by FACS. Annexin V-FITC was used to quantitate the percentage of cells within the population that are actively undergoing apoptotsis. Propidium iodide (PI) was used to distinguish viable from non-viable cells using an Apoptosis Detection Kit available from BD Pharmingen, La Jolla, CA.

FIG. 19 graphically illustrates the FACS analysis results evaluated after about 3 hours (top set of plots) and after about 24 hours (bottom set of plots). The number in the lower right quadrant of each plot represent the percentage of cells undergoing apoptosis for each treatment group. After 3 hours, about 5.39% of the intact D121 cells (i.e., no exposure to splenocytes) had undergone apoptosis. About 2.28% of D121 cells incubated with splenocytes from mice vaccinated with a control

vaccine containing only PBS buffer had undergone apoptotsis. Only about 5.19% of D121 cells incubated with splenocytes from mice vaccinated with a control vaccine comprising the empty vector DNA had undergone apoptosis. In similar fashion, about 5.15% of D121 cells underwent apoptosis when incubated with splenocytes from mice vaccinated with a control vaccine comprising the muCCL21 DNA alone; whereas about 11.46% of D121 cells underwent apoptosis when incubated with splenocytes from mice vaccinated with a control vaccine comprising the muSurvivin DNA alone. Surprisingly, after 3 hours, about 18.44% of D121 cells had undergone apoptosis when incubated with splenocytes from mice vaccinated with a vaccine of the invention comprising both muCCL21 and muSurvivin DNA.

Similarly after 24 hours, in a gated FACS analysis (gated for apoptosed cells), none of the intact D121 cells (i.e., no exposure to splenocytes) had undergone apoptosis. About 8.46% of D121 cells incubated with splenocytes from mice vaccinated with a control vaccine containing only PBS buffer had undergone apoptotsis. Only about 4.78% of D121 cells incubated with splenocytes from mice vaccinated with a control vaccine comprising the empty vector DNA had undergone apoptosis. Surprisingly, after 24 hours, about 59.2% of D121 cells had undergone apoptosis when incubated with splenocytes from mice vaccinated with a vaccine of the invention comprising both muCCL21 and muSurvivin DNA.

EXAMPLE 9. Preparation of a DNA Vaccine Encoding TIAP and Murine H60 Minor Histocompatibility Antigen Peptide.

The pBudCE4.1 vector containing TIAP and murine H60 minor histocompatibility antigen DNA (about 1 μg of pDNA) was electroporated into freshly prepared attenuated *Salmonella typhimurium* (SL2707), utilizing a Bio-Rad Pulser at 2.0 kV, 25 μF, and 100 Ohm according to the manufacturer's recommended procedures. FIG. 20 provides a schematic diagram of the expression vectors for H60 and muSurvivin incorporated in the vector.

Salmonella containing the vector were selected on zeocin-containing plates. Colonies were picked the next day and cultured overnight in LB broth (EM Science, Gibbstown, NJ) with zeocin added. The bacteria were isolated and washed in phosphate buffered saline (PBS). The washed bacteria were then suspended in

PBS medium at a concentration of about $5x10^9$ recombinant *Salmonella* per milliliter of PBS, to form a vaccine solution for later use.

Control vaccines consisting of *Salmonella* transformed with the vector alone, a vector incorporating only muSurvivin DNA, and a vector incorporating only H60 minor histocompatibility antigen (H60) DNA were also prepared according to the same procedure.

The vaccines were stored in sealed ampules until used. The plasmid DNA was stored at about -20 °C before transforming the *Salmonella*.

EXAMPLE 10. Vaccination of Mice with DNA Vaccines of Example 9.

Balb/C mice (about 8 mice per treatment group) were vaccinated with the DNA vaccines of Example 9 (about $5x10^8$ recombinant *Salmonella* in about 100 µl of PBS) by oral gavage, three times at two week intervals.

EXAMPLE 11. Cytotoxicity Assays of Splenocytes Isolated from Mice Vaccinated DNA Vaccines of Example 10.

Splenocytes were isolated from the mice vaccinated in Example 10 and were stimulated with irradiated CT-26 cells. After 5 days, the splenocytes were harvested and cytotoxic assays were preformed against CT-26 cells and Yac-1 cells (NK-sensitive T cells) at targets. The degree of cell specific lysis was determined at E/T ratios of 25:1, 50:1 and 100:1 by a 4-hour ^{51}Cr-release assay, as described in *Current Protocols in Immunology* at 3.11.4, Coligan, *et al.* Eds., John Wiley & Sons, Inc. (1994). The results are graphically illustrated in FIG. 21.

The results indicate that splenocytes from mice vaccinated with a vaccine of the present invention comprising muSurvivin and H60 DNA exhibited a two-fold or greater increases in lysis of CT-26 colorectal cancer cells compared to splenocytes isolated from mice vaccinated with the empty vector, H60 and muSurvivin control vaccines at the 100:1 E/T ratio. Very little lysis of Yac-1 was observed for all vaccines at all E/T ratios, indicating that the killing observed was likely mediated by T cells.

EXAMPLE 12. Evaluation of Tumor Resistance of Vaccinated Mice.

About 2 weeks after the third vaccination, Balb/C mice from Example 10 (about 8 mice per treatment group) were challenged with about $1x10^5$ murine CT-26 colorectal cancer cells (intravenously; i.v.).

The amount of spontaneous metastasis of CT-26 cells to the lungs was evaluated about 25 days after i.v. challenge with CT-26 cells. The mice were sacrificed and necropsied, and the tumor burdens of the lungs were evaluated by recording the average weight of the lungs from each group. A normal lung weight is about 0.2 grams. FIG. 22 illustrates typical lungs (top) removed from the vaccinated, CT-26 challenged mice. FIG. 22 also includes a graph (bottom) of average lung weight for each treatment group. A dramatic decrease in tumor burden was observed for mice vaccinated with the H60/muSurvivin vaccine of the invention compared to the control vaccines.

FIG. 23 includes a graph of percentage of mice surviving after 26 days for each treatment group. A significant increase in survival was observed for mice vaccinated with the H60/muSurvivin vaccine of the invention compared to the control vaccines.

EXAMPLE 13. Evaluation of Expression of H60 and muSurvivin in 293T cells

FIG. 24A illustrates expression of H60. 293T cells were transfected with either empty vector (V) or pH60 (H) for 24 hours, harvested and stained with NKG2D tetramer, and analyzed by flow cytometry. The transfection efficiency was about 45% as assessed by pGFP (Green Fluorescent Protein) transfection. FIG. 24B illustrates expression of muSurvivin. The 293T cells were transfected with either empty vector or pmuSurvivin for 24 hours, harvested, lysed and analyzed by western blot. The western blot indicates that muSurvivin is detectable in the transfected cells, but not in the native cells.

Part B. Vaccines From Transformed *AroA* $^-$, *dam* $^-$ Doubly Attenuated *Salmonella typhimurium*.

EXAMPLE 14. Preparation of a DNA Vaccine Encoding muSurvivin and muCCL21.

The full-length coding regions for murine survivin (muSurvivin) and murine CCL21 (muCCL21) were amplified by the reverse transcription-polymerase chain reaction using 1 μg of total RNA extracted from D121 mouse Lewis lung carcinoma cells and activated mouse splenocytes, respectively. Total RNA was extracted with the RNEASY® Mini kit (Qiagen, Valencia, CA) and RT-PCR was performed with a platinum quantitative RT-PCR thermoscript one-step system (Gibco/BRL) according to the manufacturer's instructions. Several constructs were made based on the pBudCE4.1 vector (Invitrogen) by using the PCR products designed for independent expression of two genes from a single plasmid in mammalian expression vectors. The first construct, muSurvivn/muCCL21 comprising full-length murine survivin and murine CCL21, was inserted into the multi-cloning site A between restriction sites HindIII and BamHI. Chemokine muCCL21 was generated by inserting the gene into the multi-cloning site B between restriction sites XhoI and NotI, respectively. The other vectors used for DNA vaccination were based on the first construction rather than on the absence of either muCCL21 or muSurvivin. The empty vector was generated as a control.

Protein expression of muSurvivin and muCCL21 was demonstrated by Western blottingof cell lysates following transfection of plasmids into COS-7 cells using anti-survivin and anti-CCL21 Abs, respectively. Expression of EGFP activity in Peyer's Patches of C57BL/6J mice was detected in mice after oral administration of 10^8 *Salmonella typhimurium* (*AroA* $^-$, *dam* $^-$strain RE88) transformed with pEGFP. Mice were sacrificed at time points of 8, 16, and 36 hours and fresh specimens of small intestine were removed for analysis after thoroughly

washing with PBS. Fluorescence expression of EGFP was detected by confocal microscopy.

Possible toxicities caused in the host by the attenuated bacteria were evaluated by comparing the doubly attenuated *AroA* $^-$, *dam* $^-$ strain RE88 with the single attenuated *AroA* $^-$ strain SL2707. Use of the RE88 strain resulted in the survival of all 16 mice without any obvious toxic side effects, whereas 2 of 16 mice immunized with the SL2707 strain died of toxicity and infection. Thus, the *dam* $^-$ mutation of the RE88 strain, which controls bacterial virulence, apparently rendered this strain particularly useful as a DNA vaccine carrier.

EXAMPLE 15. Oral Vaccination and Tumor Challenge of Mice with a Vaccine of EXAMPLE 14.

C57BL/6J mice were divided into five groups and were immunized 3 times at 2-week intervals by gavage with about 100 μl PBS containing about 1 x 10^8 doubly attenuated *S. typhimurium* (RE88) harboring either of the following: empty vector pBUd; individual expression vectors of either pBud-muSurvivn/muCCL21, pBud-muSurvivin, or pBud-muCCL21 along with PBS treatment groups. All mice in prophylactic treatments were challenged by i.v. injections of about 1 x 10^5 D121 murine Lewis lung carcinoma cells about 1 week after the last immunization. In therapeutic settings, mice were first injected i.v. with about 1 x 10^5 D121 murine Lewis lung carcinoma and 1 week later were subjected to 3 vaccinations with the transformed *S. typhimurium*. Mice were examined daily, sacrificed and examined for lung metastasis about 28 days after tumor cell challenge in the prophylactic setting or 63 days after the initial tumor cell inoculation in the therapeutic model.

Tumor metastasis scores following immunization with either PBS, empty vector, CCL21, survivin or CCL21/survivin vaccines, respectively, for prophylactic treatment with the vaccines are shown in Table 3. Results in Table 3 are shown as metastasis scores expressed as the % lung surface covered by fused metastatic foci: 0=none; 1=less than 5%; 2=5 to 50%; and 3= >50%. Differences in

metastasis scores between groups of mice treated with the CCL21/ survivin vaccine and all control groups were statistically significant (P=< 0.001). Inhibition of tumor growth was also observed in this therapeutic model.

Table 3. Tumor Metastasis in Balb/C Mice Challenged with D121 Lewis Lung Carcinoma Cells Post Vaccination.

Mouse Vaccination Group	Metastatic Scores
A. muSurvivin/muCCL21 Vaccine	0,0,0,0,0,0,1,1
B. Control - muSurvivin Vaccine	0,1,1,2,2,3,3,3
C. Control - muCCL21 vaccine	2,2,2,2,3,3,3,3
D. Control - empty vector vaccine	3,3,3,3,3,3,3,3
E. Control - vaccination with PBS	3,3,3,3,3,3,3

In this prophylactic setting we observed decisive suppression of disseminated pulmonary metastases of D121 murine Lewis lung carcinoma in the mice vaccinated 3 times at 2 week intervals and then challenged 1 week later by i.v. injection of tumor cells. Indeed, 6 of 8 mice completely rejected all pulmonary tumor metastases while the remaining animals revealed a markedly increased suppression of tumor metastases (see Table 3). In contrast, the survivin-based DNA vaccine lacking muCCL21 induced complete suppression of metastases in only one of 8 animals, two exhibited less than 5% metastatic tumor growth, while all remaining mice showed extensive metastatic tumor growth. Additional animals that were treated only with control vaccinations of either PBS or empty vector showed no tumor protection at all and died within 4 weeks after tumor cell challenge due to extensive metastases. Although immunization with doubly attenuated *Salmonella* carrying only the secretory muCCL21 plasmid did not dramatically suppress tumor metastasis, it still resulted in statistically significant delays of metastases when compared to controls.

Importantly, the muSurvivin/muCCL21-based DNA vaccine was also effective in markedly suppressing the growth of already well established pulmonary metastases in all experimental animals in a therapeutic setting. In contrast, all mice receiving only the muSurvivin-or muCCL21-based vaccines *per se*, or empty vector and PBS controls, revealed large disseminated pulmonary metastases of D121 non-small cell lung carcinoma in this experimental setting. Lung weights of the various experimental groups from the therapeutic model are indicated in Table 4. Normal lung weight was about 0.3 g.

Table 4. Tumor Metastasis in Balb/C Mice Pre-Challenged with D121 Lewis Lung Carcinoma Cells - Lung Weight.

Mouse Vaccination Group	Lung Weight (g)
A. muSurvivin/muCCL21 Vaccine	0.34 ± 0.06
B. Control - muSurvivin Vaccine	0.56 ± 0.09
C. Control - muCCL21 vaccine	0.86 ± 0.11
D. Control - empty vector vaccine	1.29 ± 0.4
E. Control - vaccination with PBS	1.2 ± 0.34

EXAMPLE 16. Determination of Anti-Angiogenic Effects in the Vaccinated Mice of EXAMPLE 15.

Two weeks after the last vaccination, mice were injected subcutaneously (s.c.) in the sternal region with about 500 ml of growth factor-reduced matrigel (BD Biosciences) containing about 400 ng/ml of murine FGF-2 (PeproTech, Rocky Hill, NJ) and D121 tumor cells (1 x 10^4/ml) which were irradiated with 1000 Gy. In all mice, except for 2 control animals, endothelium tissue was stained 6 days later by injection into the lateral tail vein with 200 ml of

0.1 mg/ml fluorescent *Bandeiraea simplicifolia* lectin I, Isolectin B4 (Vector Laboratories, Burlingame, CA.); about 30 minutes later, mice were sacrificed and Matrigel plugs excised and evaluated macroscopically. Lectin-FITC was then extracted from 100 ml of each plug in 500 ml of RIPA lysis and quantified by fluorimetry at 490 nm. Background fluorescence found in the two non-injected control mice was subtracted in each case.

The muSurvivin/muCCL21-based vaccine decisively suppressed angiogenesis in the tumor vasculature. A significant decrease in tumor neovascularization was observed, as indicated by Matrigel assays and quantification by relative fluorescence measured after *in vivo* staining of mouse endothelium with FITC-conjugated lectin. Macroscopically evident differences in tumor vasculaization were observed among groups treated with the muSurvivin/muCCL212 vaccine and control groups of mice upon examination of representative Matrigel plugs removed 6 days after s.c. injection of FITC-conjugated lectin. The mice vaccinated with a vaccine of the invention exhibited significantly less tumor vascularization relative to the control groups.

EXAMPLE 17. Cytotoxicity Assay.

Splenocytes were isolated from successfully vaccinated mice 5 d after tumor cell challenge. Cytotoxicity was assessed by a standard ^{51}Cr-release assay against targets of either D121 tumor cells or murine endothelial cells overexpressing survivin. To determine specific MHC class I-restriction of cytotoxicity, the inhibition evaluations were performed with 10μg/ml anti-mouse MHC class I H-2Kb/Db Abs (PharMingen, San Diego, CA).

The ^{51}Cr-release assay indicated marked cytotoxicity induced by specific CD8$^+$ T cells obtained from mice after vaccination and subsequent challenge with D121 Lewis lung carcinoma cells. The CD8$^+$ T cells isolated from splenocytes of mice immunized with either muSurvivin/muCCL21 or the muSurvivin vaccine *per se*, effectively lysed 50% and 30 % of D121 tumor cells, respectively. In

contrast, $CD8^+$ T cells isolated from control animals were ineffective in evoking any noticeable killing of tumor cells, as they showed only background cytotoxic activities. Characteristically, the $CD8^+$ T cell-mediated cytotoxicity observed was MHC class 1 antigen-restricted since the cytotoxicity was completely eliminated by the addition of anti-H2Kb/H2Db Abs.

EXAMPLE 18. Flow Cytometric Analysis and Cytokine Release Assay.

Activation markers of T cells and expression of costimulatory molecules on CD11c and MHC class II Ag-positive DCs were determined by 2 or 3-color flow cytometric analyses with a BD Biosciences FACScan. T cell activation was determined by staining freshly isolated splenocytes from successfully vaccinated mice with FITC-labeled anti-CD3e Ab in combination with PE-conjugated anti- CD25, CD28 or CD69 Abs. Activation of costimulatory molecules on APCs was measured with FITC-labeled anti-CD11c Ab and biotinylated anti-IAb Ab, followed by streptavidin-allophycocyanin, and in combination with PE-conjugated anti-ICAM-1, CD80 or DEC205 Abs. All cytometric flow experiments were performed in the presence of 0.1 μg/ml propidium iodide to exclude dead cells. All reagents for these assays were obtained from BD Pharmingen (La Jolla, CA).

Flow cytometry was used for detection of intracellular cytokines. To this end, splenocytes were collected from B57BL/6J mice about 2 weeks after D121 tumor cell challenge and cultured for about 24 hours in complete T cell medium together with irradiated D121 cells as described previously. Preincubated cells were suspended with about 1 mg purified 2.4G2 Ab (BD Pharmingen) to block nonspecific staining. The cells were washed and then stained with 0.5 mg FITC conjugated anti-CD3+ Ab. After washing 2 times, cells were fixed and stained with 1 mg/ml PE conjugated with either anti-IL2 or anti-IFN-g Abs for flow cytometric analysis. All Abs were obtained from BD Pharmingen (La Jolla, CA.).

Only the muSurvivin/muCCL21 vaccine *per se* was optimally effective in markedly upregulating the expression of CD25, CD28 and CD69 T-cell activation markers. The upregulation of CD28 is of particular importance since its interactions with B7 costimulatory molecules on DCs is known to be essential to achieve critical and multiple interactions between naïve T-cells and antigen-presenting DCs. In contrast, the DNA vaccines encoding only muSurvivin or muCCL21 *per se* increased the expression of the T-cell activation markers only 1-fold. Activation of both $CD4^+$ and $CD8^+$ T-cells by the muSurvivin/muCCL21 vaccine was also indicated by their decisive increase in intracellular pro-inflammatory cytokines IFN-g and IL-2. In comparison, PBS and empty vector controls as well as DNA vaccines encoding solely muSurvivin or muCCL21 were found to be considerably less effective in inducing these cytokines.

Upregulated expression of ICAM-1, CD80 and DEC205 on DCs, achieved by the muSurvivin/muCCL21-based DNA vaccine is particularly important since it is well known that the activation of T-cells critically depends on strong cell-cell interactions with these costimulatory molecules expressed on DCs in order to achieve optimal ligation with T-cell receptors. Again, immunization with doubly attenuated *Salmonella typhimurium* carrying eukaryotic plasmids encoding muSurvivin/muCCL21 induced the most effective up-regulation of these activation markers, which was up to 2-3 fold higher than those of controls.

EXAMPLE 19. Analysis of Tumor Cell Apoptosis.

Apoptosis in D121 tumor cells induced by vaccination was measured at about 3 hours and about 24 hours after vaccination, respectively. Both control and experimental animals were challenged i.v. with about 1×10^5 D121 cells 1 week after the last of 3 immunizations. Splenocytes were harvested from each individual mouse 1 week after tumor cell challenge, and thereafter about 2.5×10^7 splenocytes were co-cultured for 4 hours with about 5×10^5 D121 cells in 6-well plates. The ANNEXIN ®V-FITC apoptosis detection kit II (BD Biosciences Pharmingen, San

Diego, CA) was used for confirmation of early stage of apoptosis. To confirm later stage tumor cell apoptosis, about 5 x 10^5 D121 cells and about 2.5 x 10^7 splenocytes were co-cultured for about 24 hours and then analyzed by FACS for apoptosis by the TUNEL assay with the APO-DIRECT™ Kit (BD Biosciences Phramingen, San Diego, CA) according to the manufacturer's instructions.

Apoptosis was observed as early as 3 hours and with a considerable further increase after 24 hours as indicated by flow cytometric analysis of data obtained by either Annexin V or TUNEL assays. Thus, early stage apoptosis was up to 3 to 4 fold higher in groups of mice immunized with the muSurvivin/muCCL21 vaccine than in controls after splenocytes harvested from such mice were co-incubated with tumor cells. The vaccine encoding muSurvivin alone triggered apoptosis somewhat, but only one fold higher than controls. However, a dramatic 85% increase in apoptosis was observed at 24 hours only in mice immunized with the muSurvivin/muCCL21 vaccine, suggesting that a robust tumor cell immunity induced by CTLs triggered this event.

EXAMPLE 20. Preparation of a DNA Vaccine Encoding muSurvivin and H60.

A plasmid containing the full-length murine NKG2D ligand-H60 was a generous gift from Drs. A. Diefenbach and D. H. Raulet (University of California, Berkeley, CA). Expression vectors were constructed on a pBudCE4.1 (Invitrogen) backbone as described above.

Doubly attenuated *S. typhimurium (AroA* $^-$, *dam* $^-$) were transformed with DNA vaccine plasmids by electroporation as previously described hereinabove. Briefly, freshly prepared bacteria (about 1 x 10^8), at midlog growth phase, were mixed with plasmid DNA (1-2 μg) on ice in a 0.1-cm cuvette and electroporated at about 2.0 KV, 25 μF, and 100 Ω. Resistant colonies harboring the DNA vaccine vectors were cultured and stored at -80 °C after confirmation of the coding sequences.

EXAMPLE 21. Oral Vaccination and Tumor Challenge of Mice with a Vaccine of EXAMPLE 20.

Groups of BALB/c A2Kb mice (n=4-12) were immunized twice at a 2-week intervals by gavage with 100 μl PBS containing approximately 5 x 10^8 doubly attenuated *S. typhimurium* harboring the expression vectors. In prophylactic models, BALB/c mice were challenged i.v. with about 1x10^5 CT-26 cells 2 weeks after the last vaccination, and in therapeutic settings 5 days before the first vaccination. Mice were sacrificed 25 d or 28 days after tumor challenge, and lung metastasis or tumor weights, respectively were determined and compared with those of controls. The statistical significance of differential findings between experimental groups and controls was determined by Student's *t* test. Findings were regarded as significant, if two-tailed *P* values were <0.05.

Expression of H60 and muSurvivin were confirmed by transfecting 293T cells and checked by flow cytometry or Western blot analysis. The expression of H60 was confirmed by the positive staining of NKG2D tetramer. Cells transfected with Survivin tested positive as indicated by a single band at the expected molecular weight of approximately 16.5KDa. The level of NKG2D ligand expressed by CT-26 is relatively low when compared to the positive control, Yac-1 cells. Tumor cells with low levels of NKG2D ligand expression were previously reported to fail in inducing tumor rejection. In the prophylactic setting, lung weights and metastasis scores (as described hereinabove) were assessed after sacrifice of the mice 25 days after tumor challenge. The results are shown in Table 5 and Table 6. The data show that the H60 and muSurvivin vaccines individually protected the mice to some extent, whereas the combination of H60 and muSurvivin (muSurvivin/H60 vaccine) greatly enhanced protection against tumor challenges as demonstrated by significantly lower metastasis scores and decreased tumor loads in the lungs. These findings were statistically significant when compared to PBS, pBud, pH60 and pmuSurvivin control groups ($p<0.0001$, 0.002, 0.01, and 0.005, respectively).

In a therapeutic settings i.e. against established colon carcinoma metastases, lung tumor burden was assessed after sacrifice at day 28. Significantly, 8 of 12 mice treated with H60/muSurvivin vaccine survived and, more importantly, 2 of these surviving animals were completely free of metastases, while 2 others had less than 5% of their lung surface covered by fused tumor metastases. By comparison, only 2 mice survived in the empty pBud vector-treated control group, and more than 50% of the lung surface of all surviving mice was covered by fused tumor metastases. Vaccination with muSurvivin vaccine alone did not result in any significant protection in the therapeutic model, and treatment with H60 vaccine alone had only marginal therapeutic effect. The latter was suggested by a slightly improved survival rate and by one of the surviving mice having only <5% of its lung surface covered by fused tumor metastases.

Table 5. Tumor Metastasis in Balb/C Mice Challenged with CT-26 Cells After Immunization.

Mouse Vaccination Group	Metastatic Scores	No. of Mice Surviving
A. muSurvivin/H60 Vaccine	0,0,1,1,1,2	6
B. Control - muSurvivin Vaccine	1,1,1,1,2,2	6
C. Control - H60 vaccine	0,1,1,1,3,3	6
D. Control - empty vector vaccine	3,3,3,3	4
E. Control - vaccination with PBS	2,3,3,3	4

Table 6. Tumor Metastasis in Balb/C Mice Challenged with CT-26 Cells Before Immunization.

Mouse Vaccination Group	Metastatic Scores	No. of Mice Surviving
A. muSurvivin/H60 Vaccine	0,1,1,2,3,3,3	8
B. Control - muSurvivin Vaccine	3,3	2
C. Control - H60 vaccine	1,3,3	3
D. Control - empty vector vaccine	2,3	2

EXAMPLE 22. Cytotoxicity Assay.

Cytotoxicity was measured by a standard ^{51}Cr-release assay as previously described hereinabove. Briefly, splenocytes were harvested 2 weeks after the last immunization, and stimulated *in vitro* by irradiated (1,000 Gy) CT-26 cells at 37 °C for 5 days in RPMI 1640 supplemented with 10% FBS, L-Glutamine, 15mM HEPES, non-essential amino acids, sodium pyruvate, 2-ME and recombinant IL-2 at 20 U/ml (PeproTech, Rocky Hill, NJ). Splenocytes were harvested and separated with Lympholyte-M cell separation media (Cedarlane Laboratories Limited, Hornby, Ontario, Canada). Target cells were labeled with ^{51}Cr for about 1.5 hours at room temperature, and incubated with effector cells at various effector-to-target cell ratios at about 37 °C for about 4 hours. The percentage of specific target cell lysis was calculated by the formula [(E-S)/(T-S)]x100, where E is the average experimental release, S the average spontaneous release, and T the average total release.

NK activity was found to be significantly enhanced in mice immunized with H60 vaccine, and even greater NK killing was observed in mice immunized with the muSurvivin/H60 vaccine. Splenocytes from mice immunized with the muSurvivin/H60 vaccine showed the highest cytotoxicity against CT-26 target cells. In contrast, such splenocytes isolated from pBud immunized controls

revealed minimal cytotoxic killing, while those splenocytes from H60 vaccine or muSurvivin vaccinated mice *per se* showed somewhat higher cytotoxic killing. After 5 days of cell culture, NK cells did not appear to play a major roll in this cytotoxicity assay as no significant difference was seen when Yac-1 NK target cells were used, suggesting the cytotoxicity detected was mainly mediated by CTLs.

Numerous variations and modifications of the embodiments described above can be effected without departing from the spirit and scope of the novel features of the invention. No limitations with respect to the specific embodiments illustrated herein are intended or should be inferred.